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A STUDY TO EVALUATE THE EFFICIENCY OF BEAMFORMING THE LASA LONG-PERIOD ARRAY

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A STUDY TO EVALUATE THE EFFICIENCY OF BEAMFORMING THE LASA LONG-PERIOD ARRAY

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ABSTRACT

The long-period vertical-component data from 18 teleseismic earthquakes recorded at the Montana LASA were prefiltered and time-shifted to determine the amount of signal loss, rms noise reduction, and signal-to-noise ratio improvement which results from beamforming.

The results show that, for all 18 events, the average signal loss is less than 1 db, the average rms noise reduction is equivalent to a factor of $N^{\frac{1}{2}}$, and the average value of the improvement in the signal-to-noise ratio is less than 1 db below the $N^{\frac{1}{2}}$ factor.

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INTRODUCTION AND PROCEDURE

This study was conducted to evaluate the efficiency of LASA long-period beams. The data are long-period vertical-component recordings of P-wave arrivals from 18 teleseismic events that occurred between 18 November 1966 and 28 September 1967 (Table I).

The LASA long-period array consists of 21 three-component elements (one vertical and two horizontal instruments) which are located at the center of each of the subarrays which make up the LASA short-period array. For this study only the records from the vertical-component instruments of the long-period array were used (Figure 1).

The purpose of this study is to determine the amount of signal loss, rms noise reduction, and signal-to-noise gain which results from beamforming the long-period vertical-component traces for each of the 18 teleseismic events. The basic procedures include reformating the original data, prefiltering, time-shifting and summing.

Table I. Source parameters for 18 teleseismic events

EVENT	DATE	ORIGIN TIME	LOCATION LAT.	LOCATION LONG.	DISTANCE DEG.	DISTANCE KM	DEPTH KM	BACK AZIMUTH	USC&GS MAG.	N
Greenland Sea	18 NOV 66	18 48 43.9	73.4N	6.8E	51.9	5771	33	19.7	4.9	15
Kurile Islands	21 NOV 66	12 19 27.3	46.7N	152.5E	63.5	7057	40	310.9	5.6	13
Sea of Okhotsk	22 NOV 66	06 29 53.5	48.2N	146.7E	65.3	7264	453	315.1	5.6	12
South of Panama	28 NOV 66	07 32 53.4	06.6N	82.7W	43.8	4875	33	146.3	5.5	13
New Hebrides	29 NOV 66	22 17 29.9	14.7S	167.4E	97.4	10825	161	256.6	5.2	12
New Guinea	14 DEC 66	21 07 52.1	04.8S	143.9E	106.5	11836	74	281.0	6.0	13
Argentina	20 DEC 66	12 26 55.0	26.1S	63.2W	82.2	9141	589	141.7	5.7	14
New Hebrides	21 DEC 66	[illegible] 00.2	20.0S	169.7E	99.6	11071	245	251.3	5.6	13
New Guinea	23 DEC 66	15 50 20.4	7.1S	148.3E	105.2	11700	43	275.6	6.4	9
El Salvador	27 DEC 66	21 22 14.8	13.2N	88.8W	35.5	3951	66	151.2	5.5	13
Fiji Islands	19 JAN 67	12 40 14.1	15.0S	178.0W	87.9	9779	33	246.1		[illegible]
Mongolia	20 JAN 67	01 57 23.1	48.0N	102.0E	81.7	9083	33	340.8	6.1	14
South Pacific	21 JAN 67	02 54 00.8	49.8S	114.0W	95.6	10628	33	184.5	5.3	13
Peru-Brazil	20 SEP 67	09 33 54.1	8.0S	74.5W	61.3	6820	145	143.6	5.1	13
Central Mid-Atlantic Ridge	22 SEP 67	08 08 04.3	0.7S	20.1W	87.8	9767	33	93.3	5.3	13
Leeward Island	25 SEP 67	08 10 06.7	17.7N	61.5W	46.7	5196	33	112.9	4.6	13
Chile - Arg. Border	26 SEP 67	11 11 23.7	33.6S	70.5W	86.2	9580	84	150.8	5.8	13
New Britain	28 SEP 67	04 56 56.3	6.6S	153.4E	101.9	11329	44	273.0	5.9	13

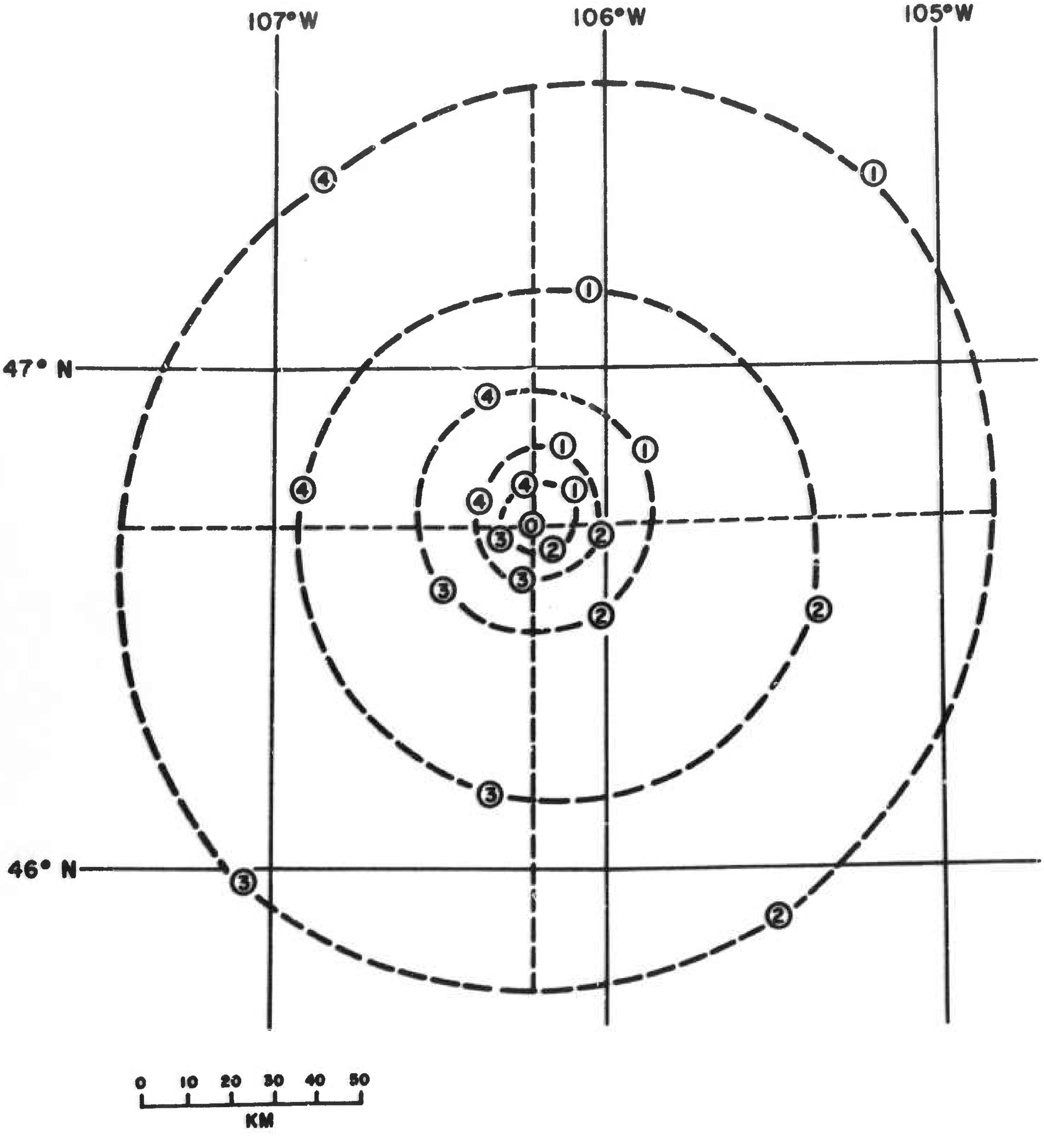

Figure 1. LASA long-period array configuration

PROCEDURE

Digital seismograms are recorded at the site in multiplex form at the rate of 800 bpi. The original magnetic tapes for the long-period seismograms are recorded in "slow mode" which has a sampling rate of 5 pps. During the period from 18 November 1966 to 28 September 1967, when the events used in this study were recorded, the long-period vertical-component seismometers at LASA were operating on response "A" with a peak sensitivity at a period of 25 seconds. A typical response curve is presented in Hartenberger (1967).

Prior to beamforming the array, the original seismograms were demultiplexed and the resulting records were detrended, demagnified, and prefiltered. The sampling rate of the demultiplexed "slow mode" tapes was reduced from 5 pps to 1 pps and the resulting time-series was converted to the SDL library format. The library tapes were detrended, thereby removing the mean. The records were demagnified to correct each trace to equivalent earth motion in millimicrons at the peak response by using the calibration data from 6 March 1967. The data were then prefiltered to the period band 15-50 seconds using a 4-pole Butterworth filter. The response curve for this recursive bandpass filter was presented in Hartenberger (1967).

In order to form the beams for the LASA long-period vertical-component array, the prefiltered traces were time-shifted to the earliest arrival by applying travel-time differences computed from the JB travel-time table and station-to-epicenter distances. The computed travel-time differences were corrected by the observed average travel-time anomalies for each epicentral area as determined by Chiburis (1966).

An earlier study by Hartenberger (1967) has demonstrated that beamforming the LASA long-period array reduces the rms noise by a factor of $N^{\frac{1}{2}}$ if the minimum sensor spacing is approximately 20-30 km. Thus, for this study, in order to obtain a minimum sensor spacing of 20 km, the B-ring of seismometers and either the C-ring or the center seismometer (AOZ) were omitted from the phased sum trace.

For each event the signal amplitude, the rms noise amplitude, and the signal-to-noise ratio were computed from the individual traces and the phased sum trace. The signal amplitude is defined as half the maximum peak-to-trough excursion occurring within a 160-second window following the onset of first motion. The rms noise amplitude is defined as the root-mean-square value obtained in a window preceding the P-wave arrival. The length of the noise sample for the events used in this study varied from 17 minutes to 75 minutes.

For each of the computed quantities, the mean value of the individual traces was compared with the value of the phased sum trace. Gains and losses, in decibels, were determined from the following formula:

$$\text{db} = 20 \log \left[\frac{\text{value on the phased sum}}{\text{mean value of individual traces}}\right]$$

RESULTS

The final results of the amplitude analysis are listed in Table II under the three headings: signal, rms noise, and S/N. The right hand column under each heading shows the gain or loss, in db, as determined by the formula given above. The final column in Table 2 shows the $N^{½}$ factor for the given event.

Figure 2 shows the loss in signal amplitude, relative to the number of sensors included in the phased sum, which results from beamforming the LASA long-period array. The signal loss is greater than 2 db for only one of the 18 events. The average value of the signal loss for all 18 events is less than 1 db.

Figure 3 shows the rms noise reduction achieved by beamforming the long-period array. The noise attenuation is plotted as a function of the number of sensors included in the phased sum. The corresponding $N^{½}$ value is indicated by the solid line. The rms noise reduction for only one of the events is less than one db relative to $N^{½}$. The average value of the noise attenuation for all 18 events is equivalent to the $N^{½}$ value.

Figure 4 presents the signal-to-noise ratio improvement resulting from beamforming the LASA long-period array as a function of the number of sensors included in the phased sum. The $N^{½}$ value is indicated by the solid line. For one of the 18 events the improvement in the signal-to-noise ratio is more than 3 db below the $N^{½}$ factor, for two of the events it is between 2 and 3 db below $N^{½}$, and for two other events it is between 1 and 2 db below the $N^{½}$ value. The average value of the improvement in the signal-to-noise ratio for all events is less than 1 db below the $N^{½}$ factor.

Table II. Amplitude data for LASA long-period array beams

EVENT	DATE	N	SIGNAL mμ MEAN	SIGNAL PHASED SUM	SIGNAL db SUM/MEAN	RMS NOISE mμ MEAN	RMS NOISE PHASED SUM	RMS NOISE db SUM/MEAN	S/N MEAN	S/N PHASED SUM	S/N db SUM/MEAN	$(N)^{1/2}$ db
Greenland Sea	18 NOV 66	15	41.1	31.8	-2.2	15.2	3.7	-12.4	2.7	8.7	+10.0	11.8
Kurile Islands	21 NOV 66	13	142.3	139.9	-0.1	17.5	4.4	-12.0	8.1	31.8	+11.9	11.1
Sea of Okhotsk	22 NOV 66	12	310.8	307.8	-0.1	12.9	3.7	-10.9	25.1	84.3	+10.5	10.8
South of Panama	28 NOV 66	13	115.2	111.2	-0.3	20.4	5.6	-11.2	5.9	19.8	+10.6	11.1
New Hebrides	29 NOV 66	12	272.7	269.6	-0.1	15.2	4.3	-11.1	18.7	63.4	+10.6	10.8
New Guinea	14 DEC 66	13	554.8	549.3	-0.1	24.6	7.6	-10.2	24.7	72.3	+ 9.3	11.1
Argentina	20 DEC 66	14	209.8	201.1	-0.4	23.9	5.9	-12.1	9.1	34.0	+11.4	11.5
New Hebrides	21 DEC 66	13	208.4	202.3	-0.3	17.4	4.3	-12.1	12.0	46.6	+11.8	11.1
New Guinea	23 DEC 66	9	1080.2	1072.5	-0.1	29.6	11.0	- 8.6	40.9	97.2	+ 7.5	9.5
El Salvador	27 DEC 66	13	163.8	161.8	-0.1	14.9	3.6	-12.3	11.0	44.7	+12.2	11.1
Fiji Islands	19 JAN 67	13	943.5	933.0	-0.1	20.0	5.7	-10.9	47.8	164.5	+10.7	11.1
Mongolia	20 JAN 67	14	1418.6	1333.1	-0.5	44.3	13.8	-10.1	37.3	96.7	+ 8.3	11.5
South Pacific	21 JAN 67	13	97.1	89.6	-0.7	28.1	6.6	-12.6	3.5	13.6	+11.9	11.1
Peru-Brazil	20 SEP 67	13	58.1	46.8	-1.9	15.6	4.4	-11.1	3.7	10.7	+ 9.3	11.1
Central Mid-Atlantic Ridge	22 SEP 67	13	59.6	52.1	-1.2	14.3	4.4	-10.2	4.3	11.8	+ 8.7	11.1
Leeward Island	25 SEP [illegible]7	13	56.6	49.6	-1.1	17.3	4.2	-12.2	3.3	1[illegible].7	+11.1	11.1
Chile - Arg. Border	26 SEP 67	13	274.4	267.0	-0.2	26.0	6.5	-12.1	10.8	41.3	+11.6	11.1
New Britain	28 SEP 67	13	763.6	751.9	-0.1	16.2	4.2	-11.8	47.5	179.7	+11.6	11.1

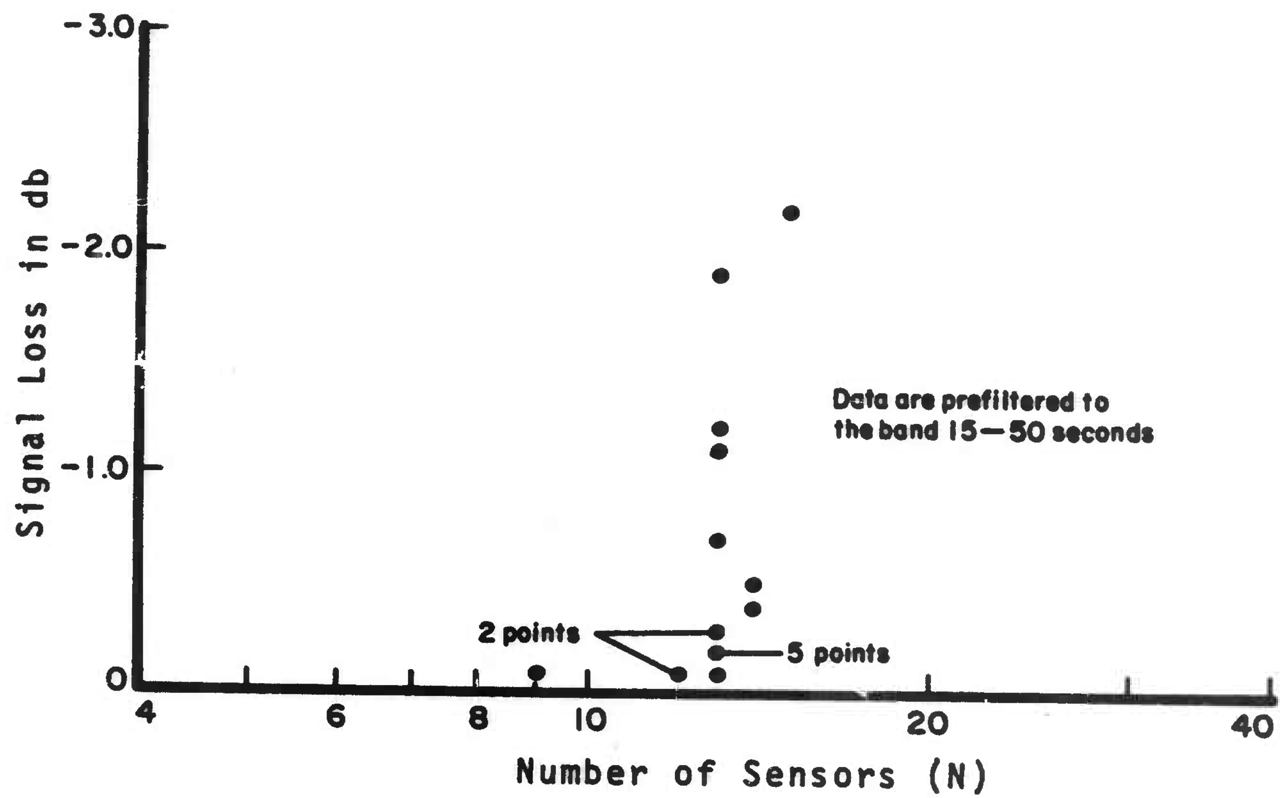

Figure 2. Signal loss by beamforming LASA long-period recordings

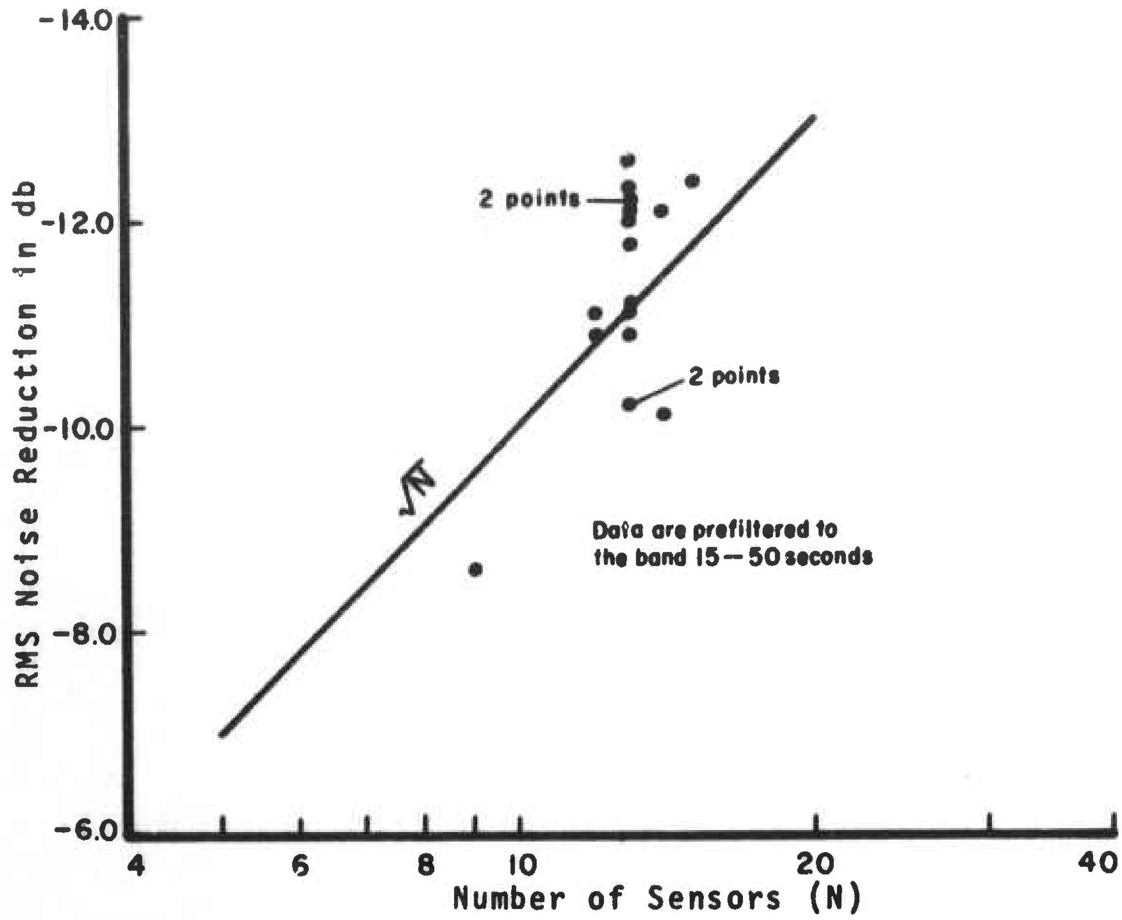

Figure 3. RMS noise reduction by beamforming LASA long-period recordings

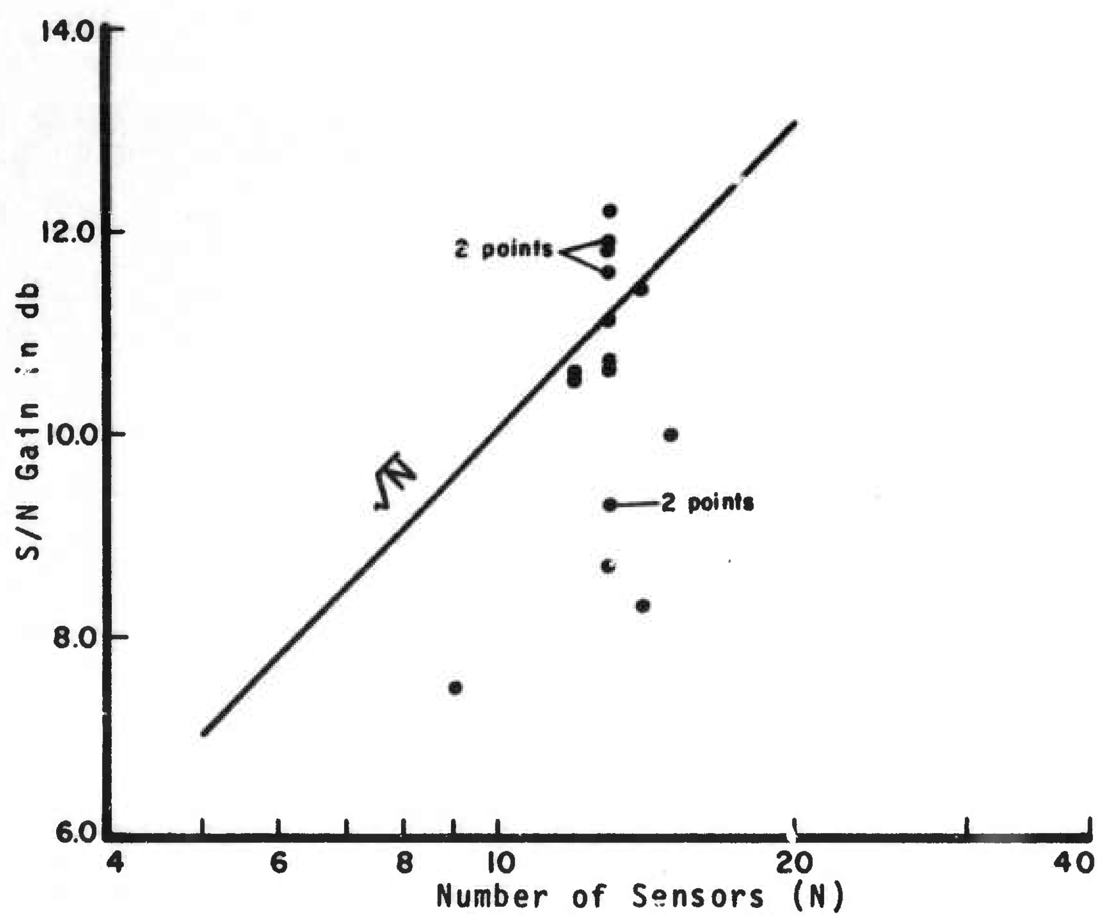

Figure 4. S/N improvement by beamforming LASA long-period recordings

Comparison of Figures 2, 3, and 4 shows: (1) the low signal/noise improvement, relative to $N^{\frac{1}{2}}$ for N = 9, is due to the low rms noise reduction, because for the same event the signal loss is very small, (2) for the event with N=15 the relatively low signal/noise improvement results from a comparatively high signal loss because for this event the rms noise reduction is equivalent to the $N^{\frac{1}{2}}$ factor, (3) for the event with N = 14 and the lower signal/noise improvement, the signal loss is very low but the rms noise reduction for the same event is also relatively low, and (4) for both events with N = 12 and N = 13 the average value of the signal/noise improvement is nearly equivalent to the corresponding $N^{\frac{1}{2}}$ value because of the low average value for the signal loss and the relatively high average value of the rms noise reduction.

CONCLUSIONS

The following conclusions are based on the results of a beamforming study which used long-period vertical-component data from the Montana LASA.

(1) For the 18 events studied, the average value of the signal loss resulting from beamforming the long-period recordings is less than 1 db.

(2) The average of the rms noise reduction for the 18 events achieved by beamforming is equivalent to the $N^{\frac{1}{2}}$ factor.

(3) The average value of the signal-to-noise ratio improvement produced by beamforming the long-period vertical-component recordings is less than 1 db below $N^{\frac{1}{2}}$.

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Hartenberger, R.A., 1967, "Power spectra and noise-reducing qualities of LASA beams", Report No. 202, Seismic Data Laboratory, Teledyne, Inc., Alexandria, Virginia.

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